Geomorphic modeling of macro-tidal embayment with extensive tidal flats: Skagit Bay, Washington

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LONG-TERM GOALS

The long term goal for the project is to better understand processes affecting morphologic changes of muddy tidal flats and to quantify the effects of tidal action, river discharge and shoreline development (e.g. dikes and jetties) on these changes.

OBJECTIVES

Our objective of this effort is to demonstrate the use of a community numerical model for prediction and investigation of tidal flat morphology and forcing parameters. The ONR/Delft community model is being evaluated as a physics-based numerical simulation tool for several investigations, and this effort applies it specifically to tidal flat and channel systems.

Within this objective, we examine the relative roles of tidal action, river discharge, and shoreline modification on flow over the tidal flats and resulting effects on morphologic modeling. From a model tuning perspective, this objective includes advancing the understanding of the sensitivity of the model to parameter value adjustments and to the inclusion or exclusion of specific sediment transport processes and characterization in tidal flat and channel systems.

The model fidelity should be improved by incorporation of observational data for configuration, assignment of boundary and initial conditions, and sediment source-term characterization, and for calibration and validation efforts.

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APPROACH

An ONR community, open-source, modeling software, Delft3d-FLOW, was used to estimate circulation, heat, salt, sand, and mud transport. Corresponding geomorphology changes also were estimated. River discharge, predicted tides, bathymetry, wind, and density-driven flow were incorporated into the model. Several simulations were conducted over the course of the last year. These simulations were designed to evaluate the sensitivity of the geomorphologic model of Skagit Bay to river typical discharges to Skagit Bay, tidal forcing, episodic discharge events and shoreline features. The circulation model has been evaluated in previous years; this year's focus has been on the evaluation of the Delft3D-FLOW sediment transport and geomorphology models.

Both Mr. Lyle Hibler and Dr. Adam Maxwell conducted model simulations. Lyle Hibler focused on project management, model experimental design, reporting, and interaction with other program participants. Adam Maxwell focused on carrying out numerical experiments, sediment transport and morphology, and data visualization and management.

WORK COMPLETED

Skagit River discharge rates were incorporated into the model as shown in Figure 1. The division of these flows between the north and south forks of the Skagit River is computed by a two-dimensional vertically averaged submodel connected to the three-dimensional bay model. This division of flow was reported previously (Maxwell et al, 2010) and at the ONR Tidal Flats Symposium (Hibler et al, 2009). The total flows are shown in Figure 1, and the three periods examined in this study (fall, winter and spring) are noted on the Figure 1. The Winter case includes flows from runoff events that peak at about 2,300 m^3/s (a 10-year flood event was estimated at Mt. Vernon to have a peak flow of about 3,228 m^3/s).[1] Hourly discharge data for the Skagit River were acquired from U.S. Geological Survey (USGS) Station 12200500.

Both mud and sand loads were applied to the north and south forks of the Skagit River according to the relationship developed by the USGS (see Equation 1 and Figure 5).[2] Initially a bed composed entirely of 1-mm sand was prescribed; while the sand introduced in Skagit River was set to 0.25 mm. This grain size is consistent with field data.[3] No bed armoring was specified. The bay bathymetry was permitted to adjust according to the redistribution of bed sand and riverine sand and mud.

$$Q_s = aQ^b \tag{1}$$

The USGS determined from observational datasets that for the North Fork the preliminary values of a and b were 5.4×10^{-8} and 3.47 and for the South Fork were 6.5×10^{-6} and 2.76. Battelle converted the values from English (as reported by USGS based on Q in cubic feet per second and Q_s in tons per day) to SI (based in Q in m^3/s and Q_s in kg/s used by Battelle). It should be noted that the formulations and parameters were preliminary. A more recent analysis in the final USGS manuscript will be reviewed and these values revised in the future analyses done by Battelle.

[1] Source: http://www.skagitriverhistory.com/PDFs/Chapter8.pdf

[2] Curran, C., E. Grossman, M. Mastin, and R. Huffman. Sediment Load and Distribution in the Lower Skagit River, Washington, USA. *Continental Shelf Research* in review.

[3] Webster, K. L., A. S. Ogston, and C. A. Nittrouer. Export and Retention of Fluvial Sediment on the Skagit River Tidal Flats, Washington State. *Continental Shelf Research in review*.)

Water temperature of the Skagit River was developed by computing an average for each day of the simulation, based on 1974-1993 water quality data from USGS Station 1220500. Water temperature at the tidal boundary was adapted from the literature.[4]

Wind forcing was applied to the circulation model; these data were made available by Washington State University.[5]

Predicted tides were applied along the southern boundary of the model (extending southeast from Crescent Harbor on Whidbey Island to the west shore of Camano Island) and along a short boundary to the west of Deception Pass on the northwest corner of Whidbey Island.[6] These northern and southern tidal elevation conditions are shown for the the Fall, Winter and Spring simulation periods. The tidal elevations are similar for each simulation. Note that the high tides in the south typically exceed those in the north. The spring tide varied about 2.4 m at Deception Pass and 3.5 m at Crescent Harbor . These tidal elevations are shown in Figures 2, 3, and 4.

The circulation model was used with the discharge and tidal conditions described above; the Winter case was also run without inclusion of the North Fork jetty. A 10-km long transect from Whidbey Island to the South Fork of the Skagit River is shown in Figure 6; the bottom elevation along this transect is shown as an inset. The channel that runs along the western edge of Skagit Bay is referred to as the gutter and extends about 1.5 km from the west edge of the transect. A 7-km shallow, broad bay flat lies east of the gutter followed by a 1.5-km irregular upward sloping shore area near the the South Fork braided channel area. This transect roughly corresponds to the one examined by Webster in her recently submitted paper.[3]

RESULTS

The simulation results, showning water level, currents, suspended sediment concentrations, and assosciated geomorphology changes for the four scenarios investigated, are presented in Figures 8 through 11.

The estimated water levels and current speeds at the 3000-m position along the transect shown in Figure 6 are shown in Figure 7 along with the Skagit River discharge used for each simulation. It is clear that, at this location, the tidal forcing is the dominant factor in modeled current speeds and that the presence of the jetty influences flows at this location at a minor level.

Along the transect shown in Figure 6, a vertically distributed sediment plume develops initially on ebb tide; as the ebb progresses, the plume migrates down into the water column at low slack. The estimated total suspended sediment concentration is shown in Figure 8 as it evolves during a representative ebb tide. These total suspended sediment concentrations are in the lower end of the range of those observed by Webster and colleagues but are consistent in general variability over a range of tidal phases. The lack of inclusion of wind wave resuspension, the specification of of sediment too coarse, and incorrect specification of boundary conditions on sediment all could cause total suspended sediment

[4] Moore, S.K., N.J. Mantua, J.A. Newton, M. Kawase, MJ Warner, and JP Kellogg. 2008. A Descriptive Analysis of Temporal and Spatial Patterns of Variability in Puget Sound Oceanographic Properties. *Estuarine, Coastal and Shelf Science* 80(4):545554.

[5] http://weather.wsu.edu (Fir Island Station). Data provided courtesy of Washington State University AgWeatherNet. Data are copyrighted by Washington State University and used in our study with permission.

[6] Source: http://www.flaterco.com/xtide

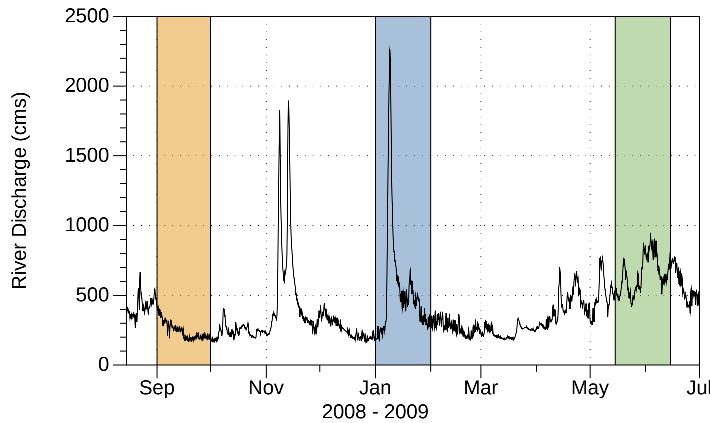

Figure 1: Hourly Skagit River discharge from USGS Station 12200500 located for each of the simulated periods in 2008 and 2009. Fall, winter, and spring simulation periods are shown in yellow, blue and green.

concentrations to be too low. This remains a topic of future investigation.

The estimated redistribution of riverine and bay sediments is shown in Figure 11. Results are shown along the transect shown in Figure 6. Three set of results are shown for days 6, 18, and 30. Curves are shown for fall, winter, and spring. The winter case with the jetty removed is also shown. After six days, the simulations begins to show a steepening of the west wall of the gutter and a deepening of the gutter in all cases examined. This indicates that the model is adjusting to a bathymetry that is more consistent with the tidal and river forcing than the initial bathymetry, or that unarmored sand is an incorrect specification for bed material in this area. For both winter cases (with and without the jetty), bathymetric adjustments between 5 and 6 km and between 8.5 and 9.5 km along the transect occur between the 6^{th} and 18^{th} days of the simulations. The only significant difference between the runs over this period is the occurrence of a runoff event in the first half of January 2009. This morphology appears to be due to increased reworking of bed sediments rather than delivery of an increased riverine sediment load associated with the episodic flow event.

Results of the study were presented previously.[7,8] Preliminary estimates of cohesive sediment fluxes over the tidal flow were estimated; the riverine flux of cohesive sediment fluxes was based on USGS data, The impact on sediment flux of the jetty near the north fork of the Skagit River was investigated. The general validity of the northward flux of sediment is being evaluated.

IMPACT/APPLICATIONS

The impact from this work will be further evaluation of the ONR/Delft community model for geomorphological simulation in an environment that is of interest to the Office of Naval Research and in the DoD-Navy, where the software is already being used for other applications. Sensitivity analyses produced in this study will be useful in assessing the data requirements for simulation in data-limited

[7] Maxwell AR, LF Hibler, and MC Richmond. 2010. Simulation of flow and sediment transport in Skagit Bay. Presented at AGU Ocean Sciences Meeting, Portland OR. PNWD-SA-8756.

[8] Hibler LF, AR Maxwell and MC Richmond. 2009. Simulation of flow and sediment transport in Skagit Bay. Presented by Lyle Hibler at ONR Tidal Flats Symposium. Boston, MA on October 28, 2009. PNWD-SA-8773.

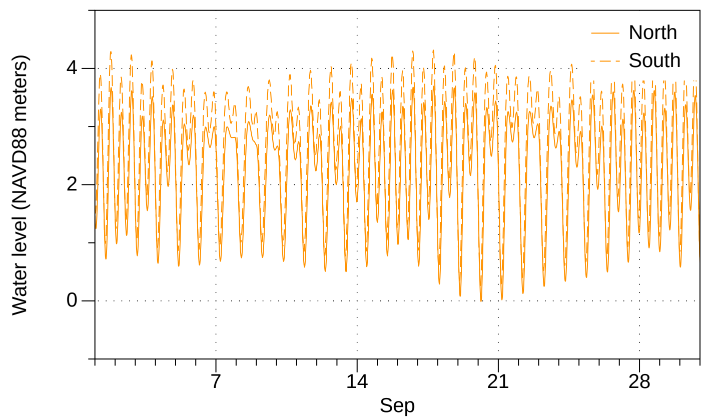

Figure 2: Predicted tides applied at north and south boundaries of model domain for Fall 2008. Skagit River discharges used during this period are shown in Figure 1.

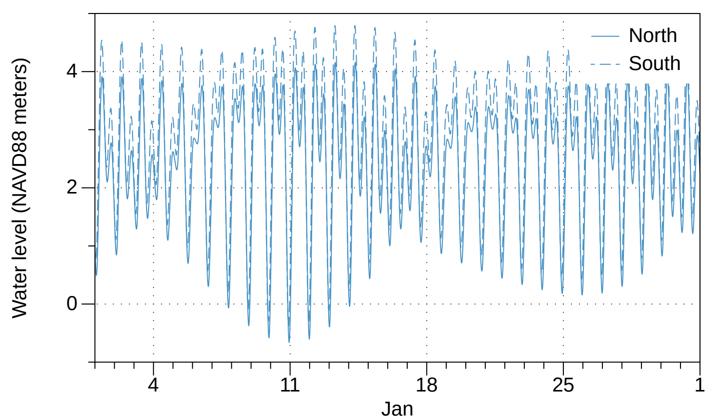

Figure 3: Predicted tides applied at north and south boundaries of model domain for Winter 2009. Skagit River discharges used during this period are shown in Figure 1.

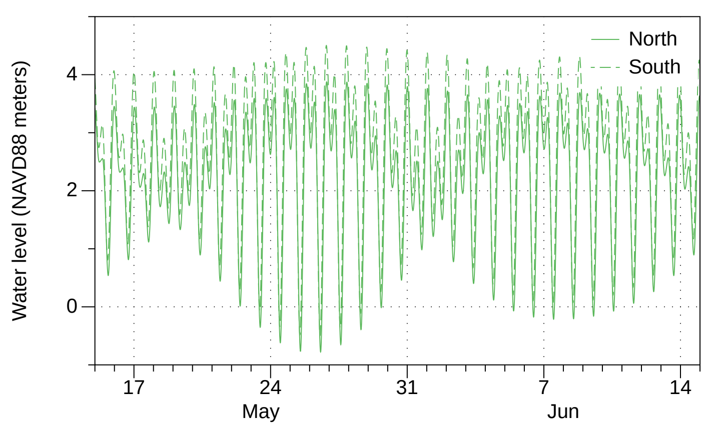

Figure 4: Predicted tides applied at north and south boundaries of model domain for Spring 2009. Skagit River discharges used during this period are shown in Figure 1.

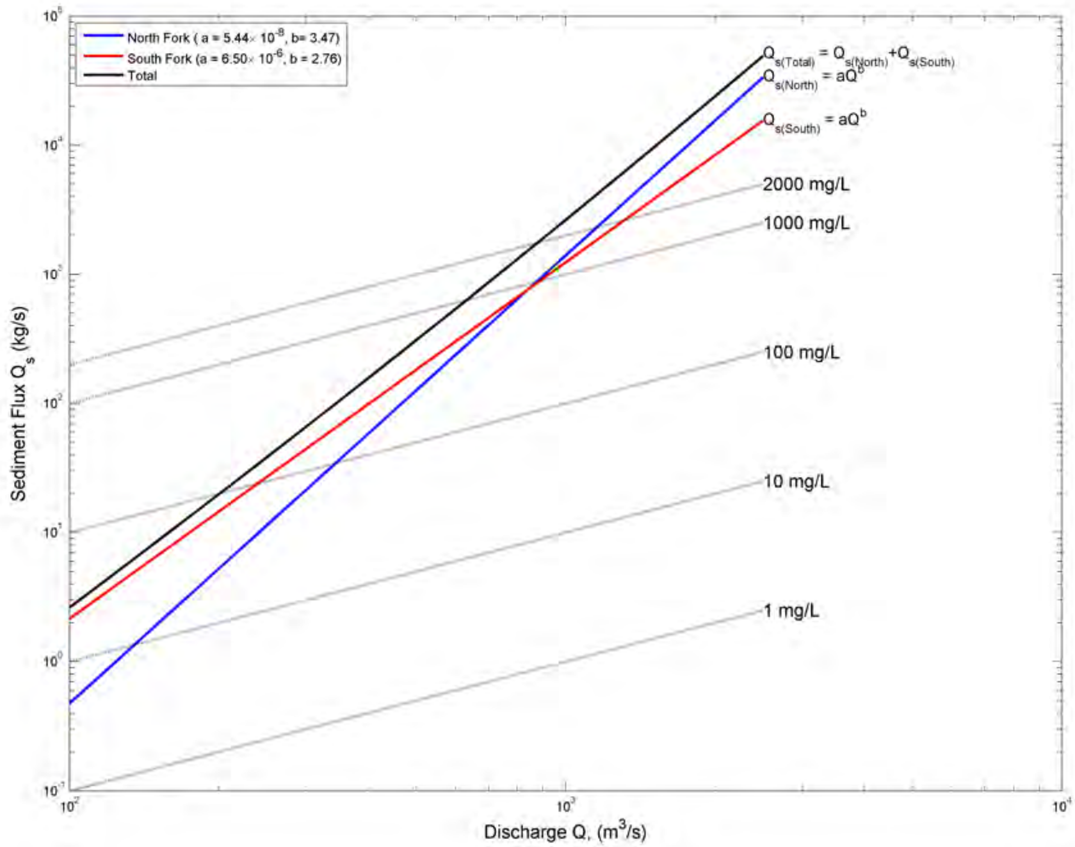

Figure 5: USGS sediment loading curves for North Fork, South Fork and total Skagit River (after Curran et al., 2011). These relationships were used to configure the sediment loading into the bay model.

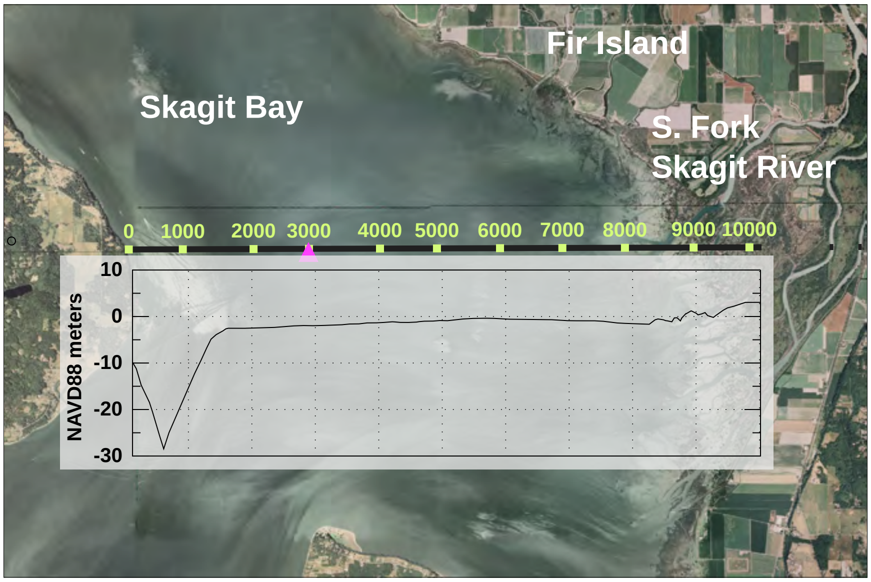

Figure 6: Depth profile across Skagit Bay near South Fork; transect distance in meters. Magenta triangle at 3000-m shows position where time varied information is shown in Figures 7 through 11

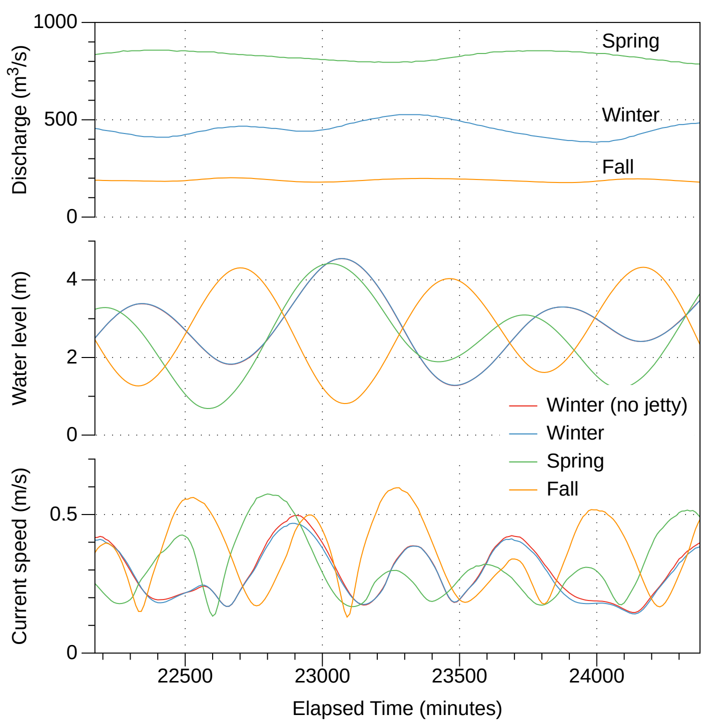

Figure 7: Skagit River discharge (top), tidal elevation (middle) and current magnitude (bottom) estimated at 3000-m position shown in Figure 6 for all simulated cases. The relative difference between key factors controlling flow and transport for the cases simulated is shown. Water level is relative to NAVD88.

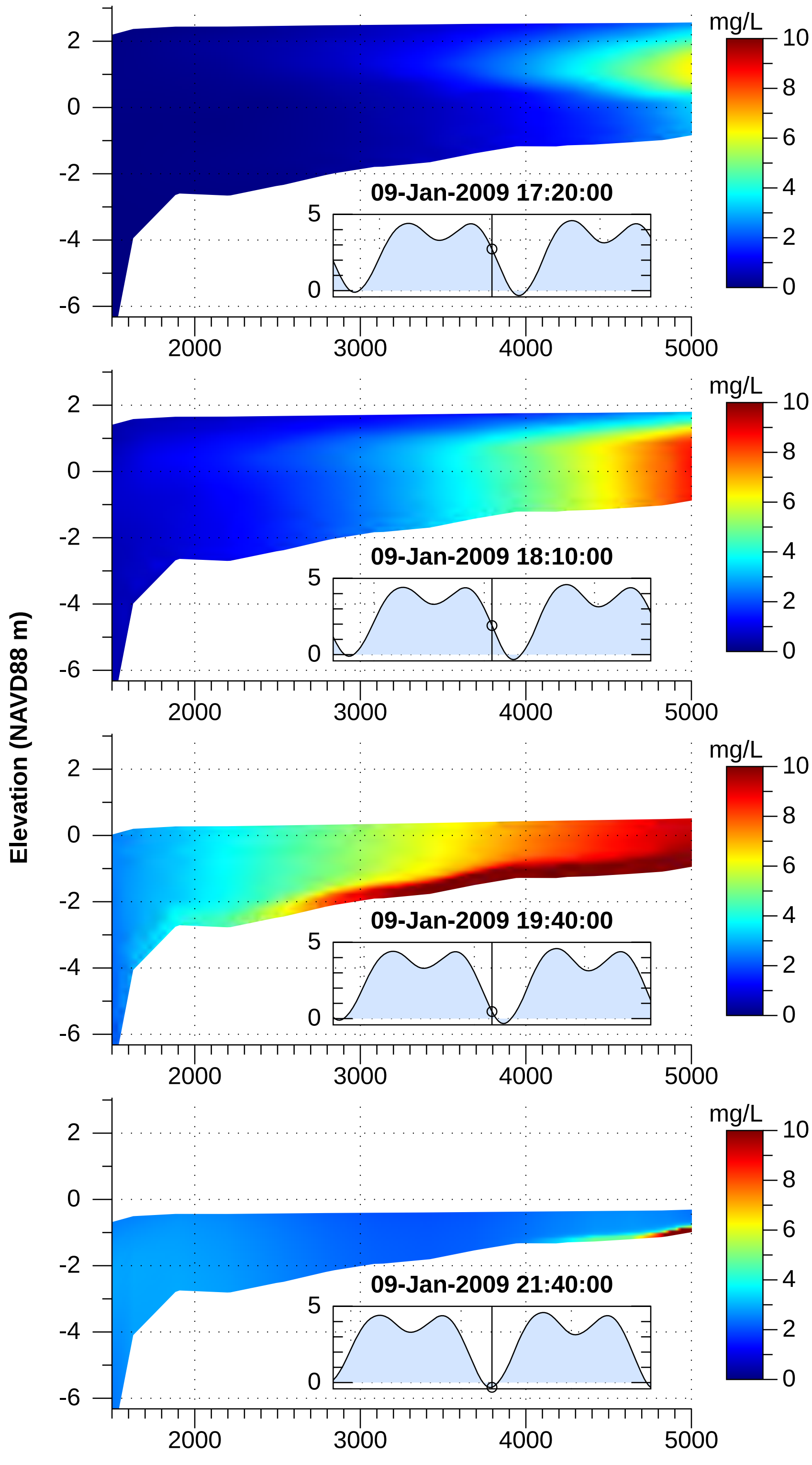

Figure 8: Total suspended sediment estimates on ebbing tide along portion of transect shown in Figure 6 for Winter conditions without jetty. All depths and distances shown are expressed in meters.

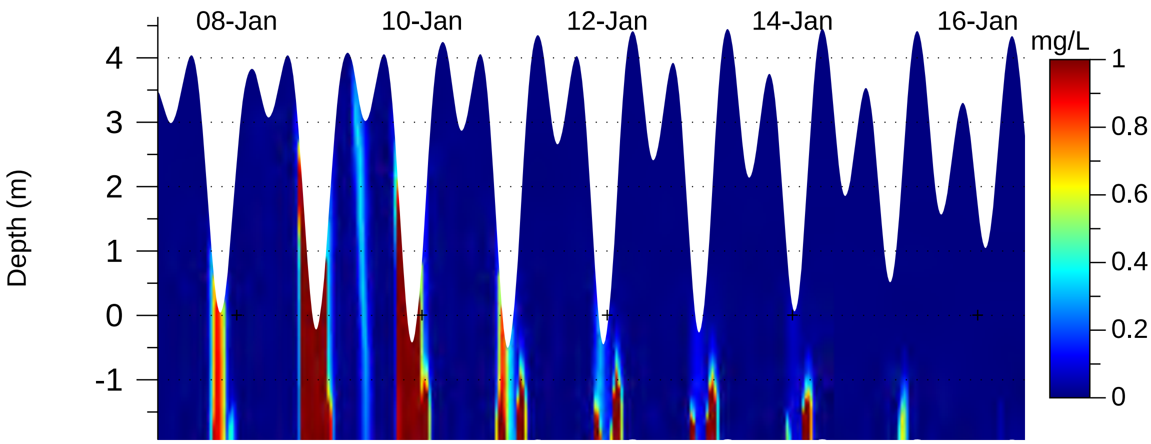

Figure 9: Total suspended sediment profiles estimated at 3000-m transect position over spring tidal period in early January 2009 including storm-event discharge shown in Figure 1; peak value is 12.9 mg/L at this location. Note magenta triangle at 3000-m on Figure 6 denotes position where time varied information is shown.

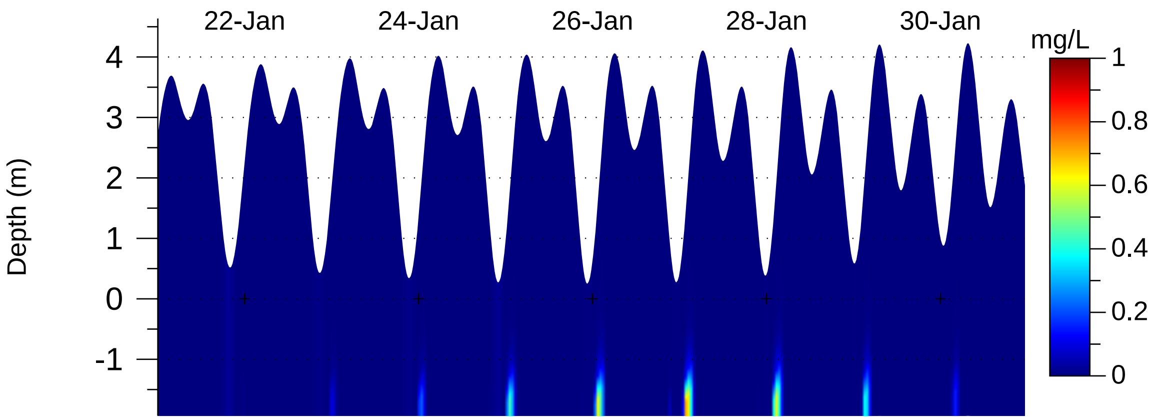

Figure 10: Total suspended solids profiles estimated at 3000-m transect position over spring tidal period in late January 2009. Note magenta triangle at 3000-m on Figure 6 denotes position where time varied information is shown.

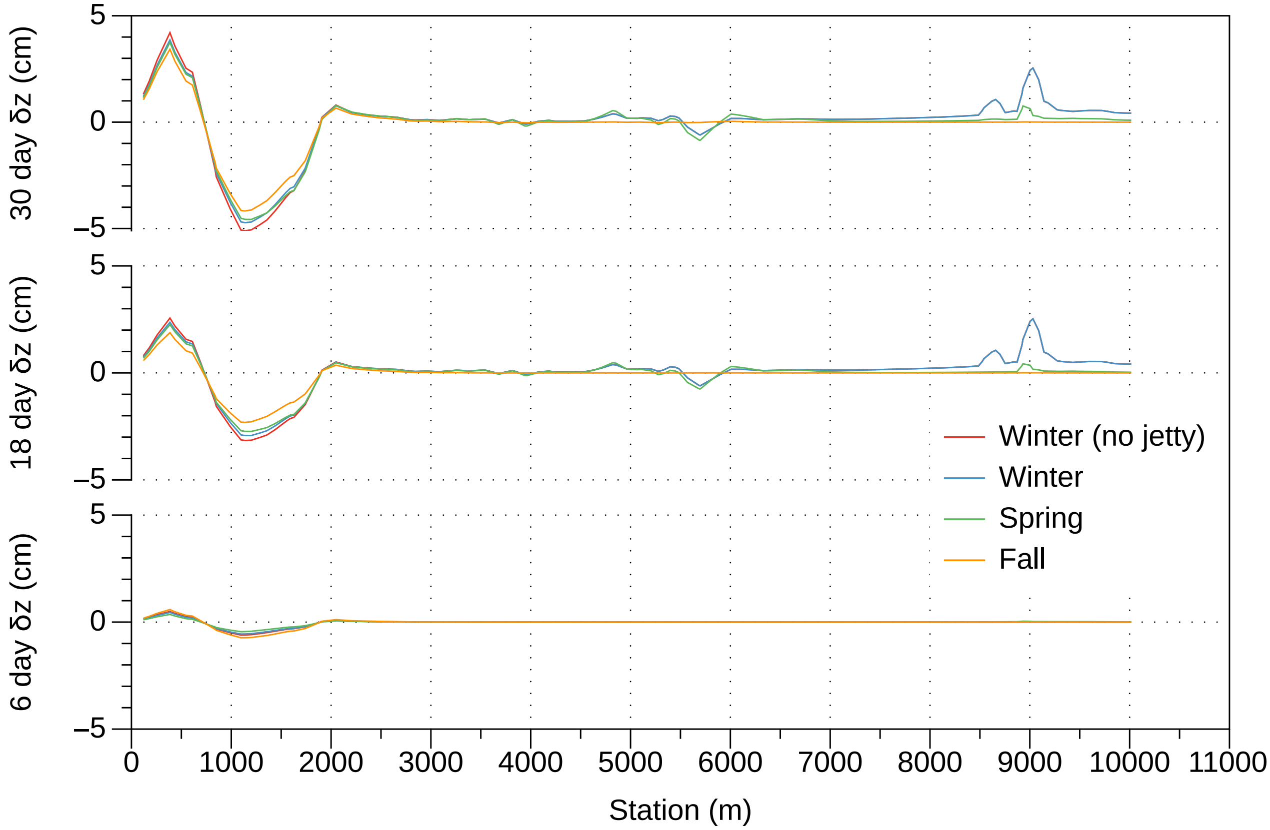

Figure 11: Bottom, middle and top panels show the estimated bed profile evolution after the simulation of 6, 18 and 30 days for each of the four scenarios investigated. The profile is the same as is shown in Figure 6. Note continued deepening of the gutter at about 1000 m and the accumulation of material over the period including the January 2009 runoff event around 5,500 m and between 8,500 and 10,000 m with little change between 18 and 30 days.

areas. The focus over the last year has been in gaining understanding of the impacts of tidal, seasonal and episodic forcing, and shoreline development on geomorphology with implications to tidal flat morphology.

RELATED PROJECTS

Concurrent modeling work is also being done to support a program entitled Observations and Modeling for Source Characterization (N000140810508) with Dr. Mark Moline (California State Polytechnic University, Dr. Eric Terrill (Scripps Institution of Oceanography (SIO)) and Dr. Ap Van Dongeren (Deltares). Lyle Hibler and Adam Maxwell will be using the same numerical modeling software to investigate the circulation with the Southern California Bight with focus on the Tijuana River plume under subtract to SIO. Integration of larger scale model (Southern California NCOM) and observational datasets will be the focus of this effort. Battelle has recently received a ONR subaward (N000141010678) to evaluate the exchange of water over reefs, into lagoons, and through reef passes in the Republic of Palau.

PUBLICATIONS

No publications.